**Course:** The Physics and Evolution of Active Galactic Nuclei

**Reading report #4**

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**Paper name:** Ram-pressure feeding of supermassive black holes

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**Paper download link:** https://www.nature.com/articles/nature23462

**Paper abstract: (copy the complete abstract here)**

When supermassive black holes at the center of galaxies accrete matter (usually gas), they give rise to highly energetic phenomena named Active Galactic Nuclei (AGN). A number of physical processes have been proposed to account for the funneling of gas towards the galaxy centers to feed the AGN. There are also several physical processes that can strip gas from a galaxy, and one of them is ram pressure stripping in galaxy clusters due to the hot and dense gas filling the space between galaxies. We report the discovery of a strong connection between severe ram pressure stripping and the presence of AGN activity. Searching in galaxy clusters at low redshift, we have selected the most extreme examples of jellyfish galaxies, which are galaxies with long tentacles of material extending for dozens of kpc beyond the galaxy disk. Using the MUSE spectrograph on the ESO Very Large Telescope, we find that 6 out of the 7 galaxies of this sample host a central AGN, and two of them also have galactic-scale AGN ionization cones. The high incidence of AGN among the most striking jellyfishes may be due to ram pressure causing gas to flow towards the center and triggering the AGN activity, or to an enhancement of the stripping caused by AGN energy injection, or both. Our analysis of the galaxy position and velocity relative to the cluster strongly supports the first hypothesis, and puts forward ram pressure as another, yet unforeseen, possible mechanism for feeding the central supermassive black hole with gas.

**Q1. What is this work all about? What is your overall impression on the quality of this work (poor, average, good, or great)? Explain briefly your assessment. [>~100 words required]**

This work is about the investigation on ram pressure effects of galaxies and its potential correlation between AGN funneling using the Multi Unit Spectroscopic Explorer (MUSE) Integral Field Spectrograph (IFS) on the ESO Very Large Telescope (VLT). My overall impression on the quality of this work is good. Firstly, the result is brand-new, which provides an interesting and novel perspective to explain AGN funneling, especially in dense environments. Secondly, the authors express their motivation, findings and methods in a neat and plain manner (as a Nature paper usually does), which makes it straightforward to read it through and understand the results.

**Q2. Why do the authors carry out this work (including, e.g., current research status, issues, scientific motivations)? [>~150 words required]**

It is widely recognized that most galaxies host a supermassive black hole (SMBH) in their galactic centers. SMBHs play significant roles in galaxy evolution, as many previous results suggest the prestigious co-evolution of galaxies with their central SMBHs, revealed by a series of scaling correlation between SMBH properties and galaxy properties (e.g. M-σ relation, $M_{BH}$-$M_*$ relation). During the cosmic evolution, SMBH would accrete matters to enlarge its size, or inversely speaking, the SMBH need to be fed on gas from the host galaxy. This is important because the ignition of the AGN mode require sufficient materials to get energized. The authors therefore make attempt to explore a possible mechanism of gas funneling to support AGN other than the circumstances of major mergers and tidal encounters between galaxies, that is, ram pressure effects in galaxy clusters. The question is to answer whether there is evidence that ram pressure effects trigger the AGN activities when galaxies fall into a dense environment filled with Intergalactic Medium (IGM).

**Q3. How do the authors manage to finish this work (including, e.g., using new data, new techniques, new models)? [>~250 words required]**

The authors use the data from the GASP (GAs Stripping Phenomena in galaxies with MUSE) Program to conduct their analysis. The GASP Program is a sub-program of the MUSE survey. It targets at 94 nearby 'jellyfish' galaxies with potential gas-only removal selected from optical images ('jellyfish' means they have prominent stripped gas tails or 'tentacles'). Although the first data release of GASP program will be publicized at the end of this year, currently there is no access to them, so the data used in this paper is new. In this study, they select seven cluster jellyfish galaxies in GASP which have conspicuous gas tails as long as or longer than the galaxy stellar disk diameter observed in Ha emission. They then derive their stellar velocity maps, Ha emission maps and diagnostic maps (the BPT classification maps). To do so, they firstly use the SINOPSIS code (algorithm: $\chi$2 minimization) to fit the stellar continuum after a careful masking for foreground sources like stars, and secondly use the pPXF code (algorithm: penalized $\chi$2 minimization) to compute stellar kinematics. Finally, emission line maps are computed using the KUBEVIZ code (algorithm: LM optimization) after subtracting continua from spectra. With the above information, the authors can immediately derived their conclusions with a combination of stellar components maps, ionized gas maps and ionization source maps. Furthermore, they use the information of the galaxy projected differential velocities and cluster-centric distances to draw a phase-space diagram to look through their candidates.

**Q4. What are the main results and conclusions of this work? What are the differences/improvements of this work compared to previous relevant works? [>~250 words required]**

Firstly, from the stellar velocity maps and Ha emission maps (Fig.1 & Fig. 2) we can see that these galaxies show clear gas stripping phenomena with their stellar components remaining unchanged, indicative of gas-only removal processes, i.e. ram pressure effects. Three of them (JO201, JO204, JW100) have double gas components, implying complicated compositions and distributions during these processes. For JO204, JW100, JO194 and JO175, their gas stripping directions are directly opposed to the cluster centers, probably suggesting their first infalling into the cluster. Secondly, from their diagnostic diagrams we can see that five of the seven galaxies in the sample show AGN ionization in their centers (two of them also showing ionization cones), while one galaxy (JO194) show LINER ionization in its center. Using the Chandra (0.3–8 keV) X-ray catalogs the authors argue that these six galaxies have AGN hosting in their centers given their X-ray luminosities. Their relatively larger EW(Ha) (> 3) and EW(OIII) further support this argument. Combining the above two results and the fact that the AGN hosting rate in low-redshift clusters is typically < 3%, the authors argue that the ram pressure effects are arguably related to AGN activities. To figure out whether ram pressure triggers the AGN or vice versa, the authors use the phase-space diagram to find these galaxies are preferably located at low radii and high differential velocity, where the ram pressure is effectively strong ($P = \rho \times \Delta v^2$). As a result, they conclude that it is the ram pressure which causes the gas inflow and eventually lead to the AGN ignition.

**Q5. What are the main contributions (i.e., scientific significances) of this work? [>~100 words required]**

The chief breakthrough and novelty of this work is that it for the first time build the connection between the ram pressure and the AGN activity. In other words, they first demonstrate that besides major mergers and galaxy encounters, the ram pressure effect in galaxy clusters might be one of (or probably makes up a large portion of, especially in clusters) the contributing factors for feeding of the central SMBH. This is counter-intuitive at first thought as the IGM actually strip the gas contents away, preventing them from cooling down to disks. However due to tidal forces some gas might lose their angular momentum and spiral into the centers, and then being swallowed by the central SMBH. Therefore, the whole picture is self-consistent and deserve further explorations in hydrodynamic simulations of ram-pressure stripping including an AGN, which have not yet been developed.

**Q6. Why can the authors make such contributions (e.g., using new idea, new data, new techniques, new theories)? [>~100 words required]**

First of all, the authors have the unique data from the MUSE-GASP Program. They have got involved in studies on these gas-stripped 'jellyfish' galaxies for a period. The exceptionally wide Field-of-View (FoV) of the MUSE survey definitely play a significant role in their studies. In contrast, other IFS surveys such as the CALIFA and MaNGA survey can only trace the galaxy radii out to 4 Re at most. Besides their new data, the main idea is simple but profound. They were probably just check the resolved BPT maps (diagnostic maps) of these galaxies and 'serendipitously' find a prevalence of the AGN hosting in these galaxies, which contradict to the established fact (common knowledge matters). Also importantly, they further demonstrate that it is ram pressure trigger the AGN activities not vice versa, making their arguments stronger and more instructive (one more step than others makes different).

**Q7. Can you think of some way to improve this work or to verify it? [>~100 words required]**

One exploration of this work can possibly be to look at why the majority (6/7) of galaxies show AGN hosting, and why the remaining galaxies do not appear AGN hosting in their centers, given most of these 'jellyfish' galaxies holding AGNs. Is it rightly in the pre-process of gas funneling before SMBH feeding? Is it a remnant of a past-AGN host since a large portion of the gas reservoir has been removed? Or some other factors might play a role. It is worth discussed about the gas-stripping timescale, the crossing timescale in clusters, the AGN illuminating timescale in galaxies. The large fraction seemingly suggest that the AGN timescale is generally longer than gas-stripping timescale (But is it true? Simulations would help us figure it out). Specially, JO201 appears not to be the first time it fall into the cluster or revolve the cluster, given its relatively strange geometry of stripped gas (opposed to the cluster center). Will it still have enough gas reservoir to support its SMBH feeding? Therefore, it deserves some further investigation.